

REMARKS

At the outset, the Applicants wish to thank Patent Examiner Mondt for the many courtesies extended to the undersigned attorney during the Telephone Interview on May 2, 2003. The substance of the Interview is set forth in the Examiner Interview Summary, dated May 2, 2003, and in this Response. Also, the Applicants wish to thank Patent Examiner Mondt and Primary Examiner Coleman for the many courtesies extended to the undersigned attorney during the Personal Interview on August 5, 2003, at the U.S.P.T.O. The substance of this Interview is set forth in the Examiner Interview Summary and in this Response.

The Patent Examiner has rejected claims 2 and 4 -6 under 35 U.S.C. 103 as being unpatentable over various combinations of *Tamatsuka U.S. Patent No. 6,291,874* in view of (newly cited) *Hongu U.S. Patent No. 6,036,932*, and further in view of *Tamatsuka U.S. Patent No. 6,299,982* and *Tamatsuka U.S. Patent No. 6,224,668*, and *Kim U.S. Patent No. 5,942,032*.

The Patent Examiner in the paragraph bridging Pages 2 and 3 of the Office Action, has stated that *Hongu* discloses that hydrogen chloride may be present in an inert atmosphere in order

to clean the silicon from boron and phosphorus. (Please see column 5 lines 61 to 65).

The Patent Examiner further states that a measurable fraction of the hydrogen atoms in hydrogen chloride disassociates into hydrogen atoms, while a large percentage of the resulting hydrogen atoms associate into hydrogen gas at the temperature of the molten silicon.

The Patent Examiner concludes that the hydrogen present along with the inert gas such as argon falls within the claimed range of the subject matter of claim 2 wherein the silicon single crystals are pulled under a hydrogen partial pressure of less than 3 mbar.

The present invention is directed to a method for producing a silicon semiconductor wafer comprising pulling a silicon single crystal from a melt, in the presence of hydrogen, using the Czochralski method, wherein the silicon single crystal is pulled under a hydrogen partial pressure of less than 3 mbar; doping the silicon single crystal with nitrogen and producing a nitrogen concentration of 5×10^{12} atcm⁻³ to 5×10^{15} atcm⁻³; and separating the silicon semiconductor wafer from the silicon single crystal.

Therefore the present invention relates to the production of a semiconductor wafer which is separated from a silicon single crystal grown according to the Czochralski method. An object of the invention is to provide a method which a) prevents aggregates of vacancies from building up an inner coating of silicon dioxide and b) to ensure that the aggregates of vacancies remain small. If the conditions a) and b) are met, the aggregates can be eliminated during a subsequent annealing step. The claimed method comprises pulling a single crystal according to the CZ-method under a hydrogen partial pressure of less than 3 mbar and doping the silicon single crystal with nitrogen. A nitrogen concentration of 5×10^{12} to 5×10^{15} atcm⁻³ is thereby established.

Hence the present invention has the advantages that the claimed method prevents aggregates of vacancies from building up an inner coating of silicon dioxide and ensures that the aggregates of vacancies remain small. In order to prevent an inner coating of the aggregates with silicon dioxide it is claimed to pull the silicon single crystal according to the CZ-method under a hydrogen partial pressure of less than 3 mbar. In addition, the silicon single crystal is doped with nitrogen having a concentration of from 5×10^{12} to 5×10^{15} atcm⁻³ in order to generate small aggregates, only.

Tamatsuka et al. (874) teach in column 6, in lines 47-51 that the wafers doped with nitrogen were subjected to a heat treatment at 1200° C for 30 seconds to out-diffuse nitrogen or oxygen present, in the wafer surface portion. As the atmosphere gas around the wafers, a mixed gas atmosphere of 75% argon and 25% hydrogen was used.

It should be evident that this teaching is completely different from the claimed invention as recited in claim 2 of the present application which relates to the preparation of semiconductor wafers by pulling a silicon single crystal and separating wafers from this single crystal. Whereas *Tamatsuka et al* disclose a specific atmosphere in the environment for the heat treatment of wafers, the present invention recited in claim 2 refers to a specific atmosphere during the pulling of a single crystal, i.e. during a stage of manufacture where wafers do not yet exist.

The present invention relates to the pulling of a silicon single crystal from a melt according to the Czochralski method. Those who are skilled in the art know that the silicon used for single crystal production has the highest purity level available on the market.

Hongu et al which has been newly cited by the Examiner deals with the purification of low-grade silicon to obtain solar cell-grade silicon (Please see column 1, lines 6-8). Solar cell-grade silicon is still not as pure as single crystal-grade silicon.

Thus, *Hongu* is nonanalogous prior art, because *Hongu* does not relate to pulling a silicon crystal by the Czochralski method.

Accordingly, the motivation alleged by the Examiner to further purify single crystal-grade silicon by adding small amounts of hydrogen chloride (HCl) does not exist. This is because the melt would be recontaminated with chlorine, the other element which is present after a dissociation of HCl. Moreover, there is a motivation to avoid the presence of HCl during the pulling of a single crystal since HCl will at least partly remove phosphorous or boron which are usually intentionally added to the melt as dopants. It is also known that HCl is a corrosive gas attacking the vessel wall, which would finally lead to a contamination of the melt with metal impurities. And finally, flushing the vessel with HCl would imply the need of an additional step for recovering the hazardous gas due to environmental reasons.

It is respectfully pointed out that an object of the invention as recited in claim 2 is to provide a method which (a) prevents aggregates of vacancies from building up an inner coating of silicon dioxide and (b) to ensure that the aggregates of vacancies remain small. The cited references do not recognize at all this problem and do not teach the claimed solution to this problem.

Tamatsuka et al. (US Patent No. 6,291,874) disclose a method for producing a silicon single crystal wafer wherein the size of so-called crystal originated particles (COP) is decreased by doping the silicon crystal with nitrogen during the pulling of the crystal according to the Czochralski method. It is theorized that the above mentioned aggregated vacancies are responsible for the formation of COP. Nevertheless, the Office Action argument that the reference discloses the teaching of pulling the single crystal in an atmosphere having a specific partial pressure of hydrogen is respectfully traversed as believed to be in error. Nowhere in this reference is there any statement about an atmosphere whatsoever which has to be established during the pulling of the silicon single crystal. Thus the reference completely fails to teach or to suggest the claimed invention.

Also this reference fails to teach how to prevent the

formation of an inner coating of the aggregates with silicon dioxide by providing a specific hydrogen partial pressure during the pulling of the crystal.

Tamatsuka et al. (874) further disclose a process step during which nitrogen is out-diffused in the wafer surface portion, (please see column 6, lines 47-51). This step is performed in a mixed gas atmosphere of 75% argon and 25% hydrogen after the wafers have been cut from the silicon single crystal. However, according to the present invention it is necessary to keep the hydrogen partial pressure in the claimed range during the pulling of the single crystal. This is because the aggregates and the inner coating of the aggregates with silicon dioxide form during this pulling period and can not be significantly influenced later after the wafers have already been cut from the single crystal. It is respectfully submitted that the Office Action has completely overlooked this essential difference between the present invention (hydrogen partial pressure during crystal pulling) and the *Tamatsuka et al.* reference (wafer cutting later from crystal).

Accordingly, it is also improper to combine information disclosed in *Tamatsuka et al.* (874) which concerns the atmosphere during an out-diffusing procedure to which wafers are subjected

with information disclosed in *Kuhn-Kuhnenfeld et al.* (US Patent No. 4,330,361) which concerns the atmosphere during the pulling of a single crystal. Moreover, *Kuhn-Kuhnenfeld et al* teach the use of a pure argon atmosphere during the pulling of the crystal and therefore clearly lead away from the second feature of the claimed method, i.e. an atmosphere containing hydrogen with a hydrogen partial pressure of less than 3 mbar.

On page 6 of the Office Action, the Patent Examiner has contended that applicant does not explain why the range for the hydrogen content of the argon-hydrogen atmosphere as defined by claim 5 is critical to the invention. In answer to this contention, it is pointed out that the claimed invention (a) prevents aggregates of vacancies from building up an inner coating of silicon dioxide and (b) ensures that the aggregates of vacancies remain small.

The deficiencies in the teachings of the primary references to *Tamatsuka et al* (6,291,874) and *Hongu*, are not overcome by the teachings of the secondary references which are the U.S. Patent No. 5,942,032 (to *Kim*), U.S. Patent No. 6,299,982 (to *Tamatsuka*) and U.S. Patent No. 6,224,668 (to *Tamatsuka*), and *Streetman*.

The *Kim* U.S. Patent No. 5,942,032 in column 10 in lines 15

to 35 discloses a method of growing vacancy rich single crystals comprising the steps of: lowering a seed crystal into contact with a melt of molten semiconductor source material in a crucible of a crystal puller; raising the seed crystal from the melt so that semiconductor material from the melt freezes on the seed crystal to form a single crystal; directing heat radiated from the side walls of the crucible to a region adjacent the surface of the melt and located below the top of the crucible for inhibiting a high instantaneous axial thermal gradient in the single crystal in the region, whereby the single crystal has no vacancy/self-interstitial boundary ring or oxidation induced stacking fault ring; thermally shielding the single crystal at a location above the melt surface to slow cooling of the crystal in the range of approximately 1150°C to 1000°C. Thus the single crystal has a predominance of vacancy defects and of agglomerated vacancy defects. Thus *Kim* fails to teach or to suggest the claimed invention.

The *Tamatsuka U.S. Patent No. 6,299,982* in column 5 in lines 36 to 48 discloses that it is important to grow the crystal at a high rate of cooling from 1150 to 1080° C. at 2.3°C./min or more. In order to actually fulfill such a condition, there can be provided an apparatus for cooling the crystal in any rate of cooling from 1150°C to 1080°C in a chamber of an apparatus for

producing a silicon single crystal by CZ method. Such an apparatus may be an apparatus which cools crystal by spraying a cooling gas thereto, or a water cooled ring which is provided so as to surround a crystal at a predetermined position above the melt. In this case, the cooling rate can be controlled in a desired range by controlling the pulling rate of the crystal.

Thus this *Tamatsuka* reference fails to teach or to suggest the claimed invention.

The *Tamatsuka U.S. Patent No. 6,224,668* in column 11 in lines 1 to 5 discloses that SOI (silicon on insulator) substrates (doped with nitrogen), were subject to a heat treatment at 1200°C for 10 seconds in an atmosphere of 100% hydrogen using a lamp heater (Steag Microtech International Corporation, SHS-2800).

Thus, a 100% hydrogen atmosphere for a silicon on insulator (SOI) substrate does not suggest the hydrogen partial pressure atmosphere of less than 3 mbar of the invention for a silicon single crystal being pulled from a melt using CZ-method.

These prior art references fail to recognize the prior art problems described in the present Specification, and fail to suggest the claimed solution to this problem as recited by all

the claims.

The present Specification on pages 3, 4 and 6 discussed this problem and provides the solution to this problem, as follows.

Although vacancy defects continue to arise in the single crystal and the semiconductor wafers separated therefrom when the prior art method is used, the formation of cavities, as have been described by *E. Iino et al.*, is not observed when the invention method is used. A hydrogen partial pressure of less than 3 mbar is particularly preferred. The partial pressure should be kept as constant as possible while the single crystal is being pulled, so that hydrogen is uniformly incorporated in the growing single crystal in the desired concentration. It should be taken into account that some of the hydrogen is driven out of the melt.

If the silicon single crystal is doped with hydrogen in the proposed concentration, the hydrogen, together with the vacancies, becomes supersaturated when the growing crystal is cooled. While the vacancies aggregate to form voids (microcavities), the hydrogen enters the voids which form or have formed. It is important that the hydrogen concentration be selected to be sufficiently low for the supersaturation which occurs. Thus the supersaturation is sufficient only for the

hydrogen to be incorporated within the voids, without separate hydrogen precipitates being formed. The optimum hydrogen concentration depends on the cooling rate of the growing crystal.

During further cooling, the hydrogen in the voids prevents the oxygen, which is likewise in a supersaturated concentration, from being able to oxidize the internal surfaces of the voids. Therefore, there is no layer of oxide formed, which otherwise is a significant factor in delaying the elimination of the voids by the heat treatment of the semiconductor wafer obtained from the silicon single crystal. A heat treatment of the semiconductor wafer may occur; however the atmosphere must contain at most only 3% hydrogen. This heat treatment is therefore sufficient to eliminate the vacancy defects in the region of the semiconductor material in which electronic components are provided.

Furthermore, it is advantageous for the volume of the vacancy defects to be kept as low as possible, so that they can subsequently be eliminated again relatively easily. This is preferably achieved by the silicon single crystal, during pulling, additionally being doped with nitrogen and subjected to forced cooling. A suitable nitrogen concentration is between 5×10^{12} and 5×10^{15} atoms cm^{-3} . The nitrogen concentration is preferably selected between 1×10^{14} and 1×10^{15} atoms cm^{-3} .

Suitable dopants are NH₃ or silicon nitride. The silicon nitride is preferably fed to the silicon melt in powder form or as a nitride-coated silicon wafer.

For all these reasons, the present invention, and all the claims, are firmly believed to be patentable under 35 U.S.C. 103 over all the prior art applied by the Patent Examiner. A prompt notification of allowability is respectfully requested; especially since the Examiner Interview Summary states that the prior art of record does not teach the invention as claimed.

Respectfully submitted,
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Enclosure: Copy Petition for One Month Extension of Time

I hereby certify that this correspondence is being deposited with the U.S. Postal Service as first class mail in an envelope addressed to: Commissioner of Patents, P.O. Box 1450, Alexandria, VA 22313-1450, on August 15, 2003.


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